IRRIGATION MANAGEMENT FOR DOUBLE-CROPPED FRESH-MARKET TOMATOES ON A HIGH-WATER-TABLE SOIL

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ABSTRACT

Two tomato (*Lycopersicon esculentum*, Mill.) experiments were conducted for two years on a southeastern Coastal Plain soil that has a high, fluctuating water table. In one experiment, two methods for managing microirrigation were compared to a treatment that received only rainfall by measuring marketable fruit yields for spring and fall cropping seasons. Irrigation increased yields for both seasons in the second year because of low rainfall. Measurements among seven shallow wells on the site showed no consistent differences for either water table depth or gradient between adjacent wells. Two cultivars were evaluated in the second year, primarily because frost severely damaged the tomato plants about three weeks after transplanting. In the second experiment, two excessively irrigated treatments were evaluated in an effort to induce a "soft-fruit" storage and shipping problem experienced by many growers in this region. Although extremely large quantities of irrigation water were applied, these symptoms were not observed in this study. There were no differences in fruit yield between the two water management treatments in either spring or fall. Fruit quality measurements showed no significant differences. The 'Sunny' cultivar performed better than 'Walter' during the fall season for the extremely wet soil condition. A double-crop, microirrigation management system has higher input costs but provides increased profitability for fresh-market tomato production, particularly where markets are available for both spring and fall crops.
KEYWORDS. Irrigation management, Tomato, Multiple crops.

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INTRODUCTION

The southeastern Coastal Plain supplies most fresh-market tomatoes for northeastern USA cities during June of each year. Irrigation is often used in much of this area, although high water tables often fluctuate near the root zone for part of the year. Sprinkler irrigation has been used extensively, but it is not well-suited to full-bed mulching systems because the polyethylene mulch inhibits uniform water infiltration. Microirrigation is becoming more popular and is replacing other irrigation types, particularly sprinkler. High costs associated with this intensive management system have caused increased interest in using the beds, plastic mulch, and irrigation system for multiple crops within a year. Also, excessively wet soil conditions, thought to be caused by a combination of sprinkler irrigation, plastic mulches, high water tables, and rainfall have been suspected of causing a physiological fruit disorder referred to as "soft-fruit" syndrome.

Various cultural practices for tomato production including seepage and microirrigation; different fertilizer sources, rates, and application methods; and alternate irrigation management techniques have been investigated in Florida (Geraldson, 1975, 1982; Locascio and Fiskell, 1983; Locascio et al., 1981; and Locascio et al., 1985). Stanley et al. (1981) reported no yield difference for tomato grown with either conventional ditch drainage or combined subsurface drainage/subirrigation on a high-water-table soil in Florida. The ditch system, however, required about twice as much water. Doss et al. (1975) found that tomato yield was unaffected by irrigation method (sprinkler, furrow, and micro) on a Coastal Plain soil in Alabama and Sweeney et al. (1987) found that neither tomato yield nor nitrogen uptake was affected by irrigation method (sprinkler and micro) in Florida. Using lysimeters, Soliman et al. (1978) found higher tomato yields with water table depths of 0.7 and 1.0 m on calcareous and sandy clay loam soils, respectively. Camp et al. (1989) reported higher yields, larger fruit, and earlier production of larger fruit for fresh-market tomato on a high water table soil in the southeastern Coastal Plain by using microirrigation, plastic mulch, staking, and good fertilization

Objectives of this experiment were (1) to evaluate the effect of cultivar and irrigation timing and amount on production of mulched, fresh-market tomato on a high-water-table soil; (2) to determine the potential for producing two tomato crops each year (spring and fall) using the same bed, plastic mulch, and irrigation system; and (3) to determine whether the physiological soft-fruit problem could be caused under field conditions by excessive irrigation.

METHODS AND MATERIALS

The experiments were conducted near Charleston, South Carolina on Yemessee loamy fine sand (fine-loamy, siliceous, thermic Aeric Ochraquult). This soil has sandy clay loam layers (between 0.25- and 0.50-m depths) overlying strongly acid loamy fine sand and fine sand which extends to the 2.0-m depth. Spring and fall crops of tomatoes were grown in two separate experiments that were conducted simultaneously, during both 1982 and 1983. Treatments for the first experiment included microirrigation controlled by a switching tensiometer and timer (labelled Automatic), microirrigation controlled manually (Manual), and rainfall only (Rainfall). Treatments for the second experiment included two levels of excessive irrigation. The volume of irrigation water applied in one treatment was double that applied in the other. This was accomplished by using either one or two tubes per bed and equal application times. These treatments were labelled Wet 1 and Wet 2, respectively. Each experiment was designed as a separate, randomized complete block with four replications. Results were analyzed statistically using analysis of variance and least significant difference procedures, with each experiment analyzed separately for each growing season.

All irrigation applications were controlled by a time clock which provided two 1.5-h periods each day (starting at 0800 and 1800) in which irrigation could be applied for a preset time period. In the Automatic treatment irrigation was applied when the gage reading of a switching tensiometer indicated soil matric potential was ≤ -25 kPa at either the 0.3-m or 0.45-m depth during the "on time". Irrigation in the Manual treatment was manually initiated when tensiometers indicated that the soil matric potential was ≤ -25 kPa at either the 0.3-m or 0.45-m depth in any two plots. Irrigation in the Wet 1 and Wet 2 treatments was initiated when a switching tensiometer at the 0.3-m depth in the Wet 1 treatment indicated that the soil matric potential was ≤ -8 kPa. The Wet 2 treatment had an equal application time, but with two tubes per bed. Consequently, it received twice as much irrigation water as the Wet 1 treatment. For the Manual treatment, the equivalent of 8 mm of rainfall for the total area was applied to the bed area (about 25% of the total area) during each irrigation event. The amount of irrigation water applied to all other treatments during each "on time" was controlled by the switching tensiometers.

Soil preparation included fall disking, moldboard plowing in the spring to 0.2 m, disking, and forming beds 1.8 m apart. Beds were then subsoiled to a depth of 0.45 m using three subsoiling shanks spaced 0.3 m apart. Fertilizer supplying 180, 101, and 191 kg/ha of N, P, and K, respectively, was broadcast within the beds in the spring and incorporated to a depth of 0.15 m. Immediately following the injection of 280-390 kg/ha of a methyl bromide-chloropicrin mixture to fumigate the soil, the beds were shaped, microirrigation tubing was installed 0.05-0.10 m deep and 0.15 m from the center, and black polyethylene mulch was placed over the beds. The microirrigation tubing was Chapin Twin-Wall with emitters spaced 0.3 m apart. Beds were prepared for the fall crop by manually removing old tomato plants (spring crop) and placing granular fertilizer supplying 157, 52, and 191 kg/ha of N, P, and K, respectively, in the resulting cavity with minimal mixing. New seedlings were transplanted through holes cut in the plastic mulch midway between previous plant locations with no additional tillage or fumigation.

In 1982 'Tempo' tomato seedlings were transplanted at a spacing of 0.45 m on 29 March (2-3 weeks following fumigation) using alternate beds. This provided a fallow bed between each plot for separation of the water management treatments. 'Walter' seedlings were transplanted at the same spacing on 2 August. In 1983 'Sunny' seedlings were transplanted on 29 March. A freeze on 20 April severely damaged all plants. Because the effect of this severe damage could not be predicted and the availability of tomato seedlings was extremely limited, another tomato cultivar, 'Duke', was transplanted on 25 April in the fallow, alternate beds. This modification essentially created a split-plot experimental design for cultivar. 'Sunny' and 'Walter' seedlings were transplanted on 1 August so that a similar experimental design, with two cultivars, could be used for the fall season. Rye was planted in rows spaced 9 m apart to provide protection from the wind in the spring; it was mowed when no longer needed, and no further growth occurred.

Yields were determined by harvesting fruit from the 12 center plants of each 7.5-m plot. Mature-green, breaker, and ripe fruit were harvested three or four times each season. Marketable fruit yield is total harvested yield less culls, which include deformed, diseased, insect-damaged, and undersized fruit. Internal fruit firmness was measured after storing six, mature-green fruit from each treatment at a constant 20° C for 12 to 15 days to allow ripening. Ripe fruit were sliced in half, and resistance of the flesh to crushing was determined with a penetrometer that had a 100-mm^2 flat tip. This procedure is described in greater detail by Karlen et al. (1983) and Karlen and Robbins (1983). For selected harvest dates in 1983, soluble solids and juice pH were determined after homogenizing fruit samples.

Seven wells about 2 m deep were installed in the experimental area to provide continuous water table measurements. Water stage recorders were installed on each cased well and were operated throughout the year except for a period of about 4-6 weeks in the early spring when they were removed for land preparation. The research site was located within 1 km of a tidal marsh and within 50 m of an irrigation supply pond; tidal effects on the water table were not expected based on previous results at this location (Camp et al., 1989). Consequently, changing recorder charts on a monthly interval provided adequate resolution with respect to time. Tensiometers were installed at 0.15-, 0.3-, 0.6-, and 0.9-m soil depths in all water management treatments. Tensiometer measurements were recorded at least twice weekly. A recording rain gauge continuously measured on-site rainfall throughout the year. Applied irrigation water was measured with in-line, positive displacement water meters.

Differences in water table elevations among the seven wells at selected times were determined using variance, correlation, interpolation, and regression techniques. Differences between water elevation in individual wells and the mean water elevation for all seven wells were calculated and graphed for each well during the season. To determine the potential for water movement among wells, water-table gradients between adjacent wells (in all combinations) were calculated from elevation differences at a specified time each day and the appropriate distance between wells. Both magnitude and direction of all gradients were then compared for each day throughout the season. Water table data were analyzed in the same manner as in a previous experiment at this location and are described in detail by Camp et al. (1989).

Results and Discussion

Water Table and Rainfall

Water table elevations in the seven wells were very similar during both years, although there were small differences among wells. All water table elevations changed primarily with rainfall events, but response time varied among wells. Mean water table depths computed from interpolated elevation data are shown for 1982 and 1983 in figures 1 and 2, respectively. The water table during the 1982 growing season (29 March-5 November) was high most of the year, generally fluctuating in the range of 0.5 to 1.0 m deep. The water table briefly dropped to about 1.2 m once (May) but by 1 June it returned to a depth of about 0.8 m. The water table was generally higher during fall than during spring, fluctuating in the range of 0.5 to 0.7 m. Rainfall during 1982 was moderately high with fair distribution (fig. 1). Rainfall amounts for spring and fall growing seasons (640 and 403 mm, respectively) are shown in Table 1.

In 1983 the water table was lower than in 1982 for both the spring and fall seasons, reaching a maximum depth of 1.5 m near the end of June (fig. 2). Although the water table was high in the early spring (0.5 m), it dropped rapidly until June when it reversed the downward trend and fluctuated in the 1.0- to 1.3-m depth range during the fall season. The greater water table depths in 1983 were caused by the much lower rainfall amounts during both spring and fall (436 and 294 mm, respectively) (Table 1). In both years the water table responded primarily to rainfall. Rainfall events of 25 mm or greater generally caused the water table to rise, but after 1-5 days without significant rainfall the decline continued.

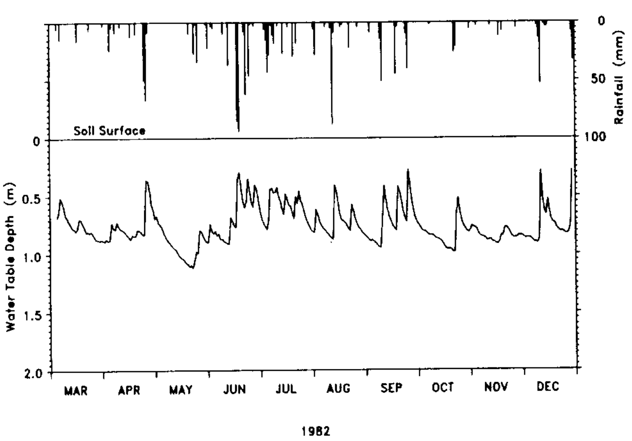

Figure 1–Mean water table depth for seven wells on a southeastern Coastal Plain soil for 1982.

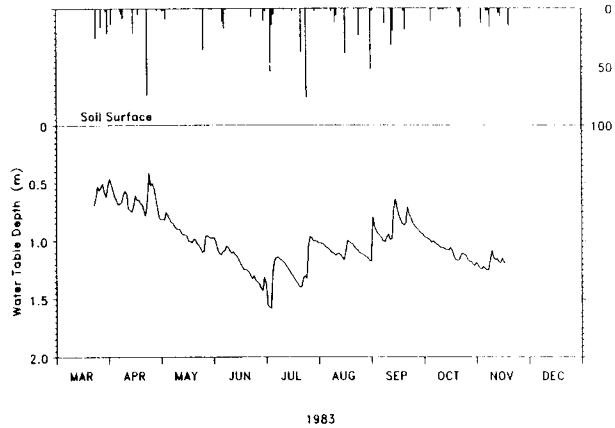

Figure 2–Mean water table depth for seven wells on a southeastern Coastal Plain soil for 1983.

As in a previous experiment at this location, differences in water table elevations among individual wells were generally small except following significant rainfall (Camp et al., 1989) confirming that the water table at this site is influenced predominantly by rainfall. Compared to rainfall the daily influence of tides on the water table elevation was negligible.

Irrigation Management Experiment

Growing-season rainfall and irrigation amounts and the number of events for both 1982 and 1983 are shown in Table 1. Total irrigation applied was much higher in 1983 for both the spring and fall seasons because of lower rainfall. There was little difference in the amount of water applied for the two irrigation treatments, both within seasons and between the spring and fall seasons in 1982. In 1983, much more irrigation water was applied in the Automatic treatment than in the Manual treatment. Less rainfall in 1983 substantially increased the need for irrigation, but control equipment malfunctions in the Automatic treatment caused excessive irrigation amounts to be applied.

TABLE 1. Growing-season rainfall and amounts of irrigation applied to fresh-market tomatoes during the spring and fall seasons in 1982 and 1983

Year/	Spring		Fall	
Treatment*	Rainfall	Irrigation	Rainfall	Irrigation
	mm			
1982				
Automatic	640 (25)†	89 (14)	403 (22)	79 (11)
Manual	640 (25)	73 (9)	403 (22)	99 (12)
Rainfall	640 (25)	—	403 (22)	—
1983				
Automatic	436 (28)	710 (32)	294 (23)	403 (34)
Manual	436 (28)	227 (15)	294 (23)	262 (19)
Rainfall	436 (28)	—	294 (23)	—

* Treatment definitions are as follows: Automatic = daily application controlled by timer and switching tensiometer at the 0.3-m depth; Manual = irrigation controlled by operator based upon tensiometer values at the 0.3-m depth in two plots; Rainfall = rainfall only.

† Numbers in parentheses refer to the number of rainfall or irrigation events.

Soil matric potential at the 0.3-m depth remained high during the entire spring season in 1982 for the Automatic treatment but reached a relatively low level (about –80 kPa) for a two-week period in June for the Manual treatment. Values were also high during the fall season for both irrigation treatments except for a two-week period in October when they were –20 to –60 kPa (fig. 3). In 1982 the Rainfall treatment had low soil matric potentials in the spring season (–60 to –80 kPa) but had higher potentials in the fall season. Soil matric potentials at the 0.3-m depth during the 1983 spring season were similar to 1982 values for the Automatic treatment (fig. 4), although much more irrigation water was applied. Soil matric potentials for the Manual treatment were lower on several occasions during the 1983 spring season (–40 to –60 kPa), which was probably caused by short delays in manually starting the system. Soil matric potential values for the Automatic treatment also reached low values on several occasions during the fall season in 1983, even though large amounts of irrigation water were applied. Matric potentials for the Rainfall treatment in 1983 were very low throughout both the spring and fall seasons, reflecting the dry growing seasons.

The higher water table in 1982 did not have a significant effect on soil matric potential at the 0.3-m depth, but it probably affected soil matric potential at the 0.6- and 0.9-m depths and possibly provided water for uptake by tomato roots. Positive matric potentials at deeper soil depths (> 1 m) confirm that the water table was above the deeper tensiometers. Soil at the 0.3-m depth generally did not reflect the effect of water table fluctuations. Because irrigation was managed using tensiometer readings at that depth, some excess irrigation water could have been applied, but the amount should have been small because most water is withdrawn from the surface 0.3-m layer of soil. The large amount of irrigation water applied in the Automatic treatment in 1983 did not cause excessively wet conditions in the root zone or significantly affect water table elevation.

Marketable tomato yields for 1982 are shown in Table 2. When compared to a 'normal' yield of 45 Mg/ha all yields were high (52-62 Mg/ha) for both spring and fall seasons, and irrigation had no significant effect on tomato yield, either in size or total yield. Yield for the fall season was equal to that for the spring season, indicating excellent potential for two crops each year provided markets can be identified. Similarly, there were no significant yield differences for the first harvest in either the spring or fall seasons, indicating no significant treatment difference with respect to earliness (data not reported).

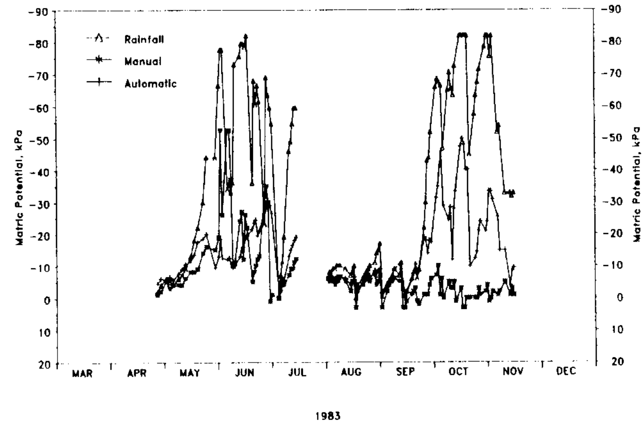

Figure 4–Soil matric potential at the 0.30-m depth for two irrigation and one rainfall-only treatments in 1983.

In 1983, all irrigated treatments again produced high yields (50-60 Mg/ha) in both spring and fall seasons. Total yields and those in the extra-large and large classes were significantly higher for the irrigated treatments during the spring season (Table 3). In the fall, yields in the extra-large and large classes were significantly higher for both irrigated treatments than for the Rainfall treatment, but total yield was significantly higher only for the Automatic treatment. Again, irrigated yields for the spring and fall seasons were similar.

There was no significant difference in yield between 'Sunny' and 'Duke', although 'Sunny' plants were severely damaged by freezing temperatures in the spring season (Table 4). There was essentially no height difference between the two cultivars by 1 June, providing further evidence of the recovery of the 'Sunny' plants from the freeze damage. In the fall season, yields in the extra-large and large classes were significantly higher for

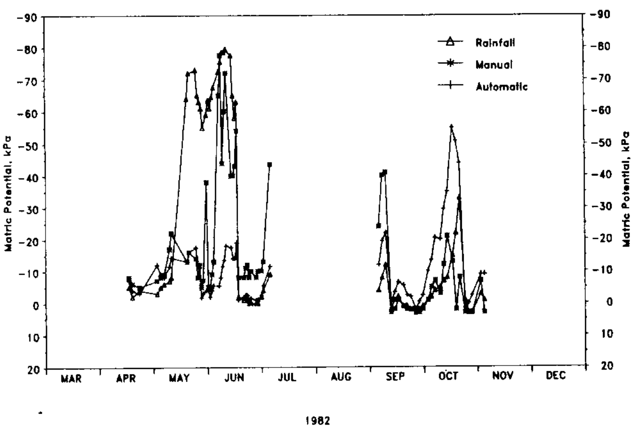

Figure 3–Soil matric potential at the 0.30-m depth for two irrigation and one rainfall-only treatments in 1982.

TABLE 2. Water management effects on size and total marketable fruit yield of 'Tempo' (spring) and 'Walter' (fall) in 1982

		Size*				
Treatment	Crop	XL	L	M	S	Total
		Mg/ha				
Automatic	Spring	40.86 a†	17.91 a	3.20 a	0.48 a	62.46 a
Manual	Spring	35.25 a	21.21 a	1.74 a	0.48 a	58.68 a
Rainfall	Spring	33.60 a	16.36 a	1.84 a	0.48 a	52.29 a
Automatic	Fall	14.23 a	31.37 a	11.46 a	4.45 a	61.52 a
Manual	Fall	13.90 a	29.94 a	10.96 a	3.39 a	58.18 a
Rainfall	Fall	14.36 a	28.64 a	11.47 a	3.84 a	58.31 a

* XL = extra large > 73 mm; L = large 64-73 mm; M = medium 59-64 mm; S = small 54-58 mm; Total = sum of all sizes.

† Means followed by the same letter within a column for the same season are not significantly different at the 0.05 level using least square differences and analysis of variance.

TABLE 3. Water management effects on size and total marketable tomato fruit yield averaged across cultivars in 1983

Treatment	Crop	Size* XL	L	M	S	Total
		--------Mg/ha--------				
Automatic	Spring	38.31 a†	21.80 a	2.16 b	0.31 b	62.57 a
Manual	Spring	29.79 a	19.60 a	2.23 b	0.34 b	51.97 a
Rainfall	Spring	4.42 b	12.68 b	4.13 a	1.13 a	22.35 b
Automatic	Fall	8.27 a	31.21 a	14.42 a	5.07 a	58.97 a
Manual	Fall	7.10 a	25.80 a	12.21 a	5.10 a	50.22 ab
Rainfall	Fall	1.76 b	17.21 b	12.61 a	5.10 a	36.69 b

* Abbreviations and sizes are the same as defined in Table 2.

† Means followed by the same letter within a column for the same season are not significantly different at the 0.05 level using least squares differences and analysis of variance.

'Sunny' than for 'Walter'. Significant damage resulted from disease during the 1983 fall season in one area of the experimental site. The infestation did not appear to be related to any treatment.

Measurements indicated no significant difference in fruit firmness among treatments in 1982 for any harvest, in either the spring (0.9-2.6 kg/cm^2) or fall (0.9-1.8 kg/cm^2) season, and there was no indication of "soft-fruit" syndrome. In 1983, there were no differences in fruit firmness among the water management treatments in either season (1.4-4.5 kg/cm^2) or between 'Sunny' and 'Duke' in the spring (1.7-4.5 kg/cm^2). However, firmness measurements were significantly higher for 'Sunny' than for 'Walter' at every harvest during the fall season. Firmness values for 'Walter' were well within the acceptable range (1.4-1.8 kg/cm^2), indicating a cultivar difference, not 'soft-fruit' syndrome. There were no differences in soluble solids among treatments or cultivars in the spring season, but the Rainfall treatment had significantly higher values than the two irrigated treatments for the first three fall harvests. Similarly, 'Walter' had higher soluble solids for the same three harvests in the fall. There were no differences in acidity for any harvest or seasons, but 'Walter' had higher acidity at the first two fall harvests.

TABLE 4. Cultivar effect on fruit size and total marketable fruit yield in 1983

Cultivar	Cropping Season	Size* XL	L	M	S	Total
		--------Mg/ha--------				
'Sunny'	Spring	27.53 a†	16.10 a	2.42 a	0.52 a	46.54 a
'Duke'	Spring	20.82 a	19.99 a	3.26 a	0.66 a	44.72 a
'Sunny'	Fall	8.16 a	28.95 a	10.48 b	3.04 b	50.63 a
'Walter'	Fall	2.47 b	19.03 b	15.59 a	7.15 a	44.23 a

* Abbreviations and sizes are the same as defined in Table 2.

† Means followed by the same letter within a column for the same season are not significantly different at the 0.05 level using least squares differences and analysis of variance.

TABLE 5. Rainfall and amounts of irrigation applied to fresh-market tomatoes in two excessively irrigated treatments during spring and fall seasons in 1982 and 1983

Year/ Treatment*	Spring Rainfall	Spring Irrigation	Fall Rainfall	Fall Irrigation
	--------mm--------			
1982				
Wet 1	640 (25)†	123 (25)	403 (22)	179 (25)
Wet 2	640 (25)	262 (25)	403 (22)	380 (25)
Rainfall	640 (25)	—	403 (22)	—
1983				
Wet 1	436 (28)	428 (26)	294 (23)	342 (34)
Wet 2	436 (28)	511 (26)	294 (23)	615 (33)
Rainfall	436 (28)	—	294 (23)	—

* Treatments are defined as follows: Wet 1 = daily irrigation application via 1 tube / bed controlled by switching tensiometer and timer; Wet 2 = daily application via 2 tubes / bed (double Wet 1 application) when Wet 1 treatment was irrigated.

† Numbers in parentheses refer to the number of rainfall or irrigation events.

Excessive Irrigation Experiment

Rainfall and irrigation applications for the two excessive irrigation treatments (Wet 1 and Wet 2) are included in Table 5. Spring and fall irrigation amounts were similar both years, but approximately twice as much irrigation water was applied to all treatments in 1983. The difference in irrigation amounts between the two treatments during spring 1983 was not as great as planned because of equipment problems, but the difference was about as planned during the fall season. Tensiometer data indicated that the soil in both 'Wet' treatments had a high water content at all depths during both the spring and fall seasons in 1982 (fig.5). In 1983, the soil in the Wet 1 treatment was much drier (–30 to –70 kPa) at depths less than 0.45 m during the last half of the spring season (fig. 6). In the Wet 2 treatment, the soil remained wet (0 to –10 kPa) at all depths, except for the latter part of both seasons when it was drier (–20 to –50 kPa) at depths shallower than 0.30 m. Higher water table elevations (fig. 1) undoubtedly had a significant influence in 1982.

Marketable tomato yields for the Wet 1 and Wet 2 treatments in 1982 are reported in Table 6. There were no

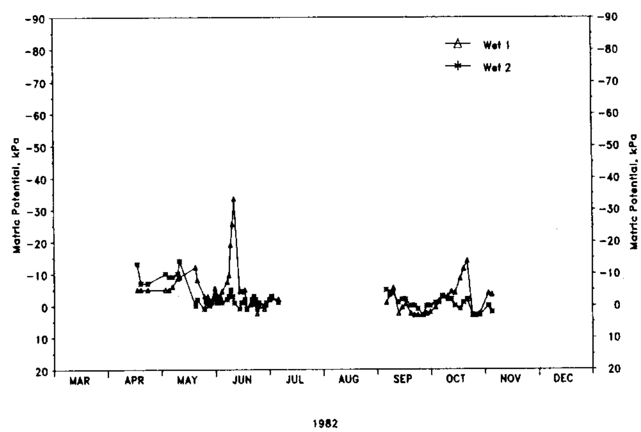

Figure 5–Soil matric potential at the 0.30-m depth for two excessive irrigation treatments in 1982.

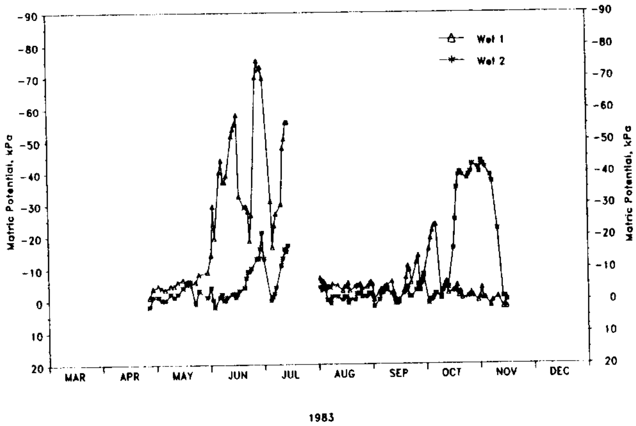

Figure 6–Soil matric potential at the 0.30-m depth for two excessive irrigation treatments in 1983.

significant differences in yield within size classes or for total yield, and all yields were comparable to those obtained with better water management (Table 2). Maturity was also not affected since there was no difference between the two treatments at the first harvest.

In 1983, all yields were slightly higher than in 1982. There was no significant difference between the two irrigation treatments in either season (Table 7). There were significant yield differences between 'Sunny' and 'Walter' (Table 8) during the fall season. Total yield, as well as yield in the extra-large and large classes, was greater for 'Sunny'.

Excessive irrigation caused a significant difference in fruit firmness (data not presented) at only one harvest in 1982, but all values were well within the acceptable range. In 1983, there were no significant differences in fruit firmness between water management treatments or between cultivars for any harvest in either season (Table 9). Again, all values were within the acceptable range, with no indication of "soft fruit" syndrome.

There were no significant differences in soluble solids (data not presented) between the two water management treatments for any harvest in 1982. Soluble solids for 'Sunny' were significantly higher than for 'Duke' for two harvests in the spring of 1983. Soluble solids were significantly higher for 'Walter' than for 'Sunny' in two fall harvests. There were no significant differences in acidity between the two water management treatments or between cultivars (Table 9). Consequently, we conclude that the excessive irrigation treatments caused no consistent difference in fruit quality although there may be minor differences between cultivars. Excessive irrigation, however, is costly and may increase leaching losses of plant nutrients and lead to ground water contamination.

Very large quantities of irrigation water were applied on soils with a high water table, but the 'soft-fruit' shipping and storage problem encountered by tomato growers in this region was not developed in this experiment. It was hypothesized that "soft-fruit" syndrome may be caused by excessive soil water and/or poor N fertility management, but as in a previous two-year experiment at this location, these symptoms did not appear when irrigation was properly managed. Karlen et al. (1983) were able to induce similar symptoms by flooding tomatoes grown in a greenhouse, but the "soft-fruit" syndrome characteristics were not induced in four years of field experiments. These studies and other work would suggest that for onset of this problem, water-logging would have to be severe enough to cause wilting and stomatal closure. Extensive measurements of leaf diffusive resistance and xylem pressure potential from this study showed no relationship between treatment and these physiological indicators. This would suggest that water tables would need to rise well into the root zone for prolonged periods to induce the kinds of

TABLE 7. Excessive irrigation effects on fruit size and total marketable tomato fruit yield averaged across cultivars in 1983

Treatment	Cropping Season	Size* XL	L	M	S	Total
		----------Mg/ha----------				
Wet 1	Spring	36.06 a†	22.42 a	2.30 a	0.66 a	61.44 a
Wet 2	Spring	37.67 a	24.48 a	2.51 a	0.25 a	64.92 a
Wet 1	Fall	7.33 a	28.32 a	15.75 a	8.32 a	59.71 a
Wet 2	Fall	6.15 a	26.99 a	16.86 a	8.23 a	58.23 a

* Abbreviations and sizes are the same as defined in Table 2.
† Means followed by the same letter within a column for the same season are not significantly different at the 0.05 level using least squares differences and analysis of variance.

TABLE 6. Excessive irrigation effects on fruit size and total marketable fruit yield of 'Tempo' (spring) and 'Walter' (fall) in 1982

Treatment	Cropping Season	Size* XL	L	M	S	Total
		----------Mg/ha----------				
Wet 1	Spring	35.54 a†	18.20 a	2.23 a	0.29 b	56.26 a
Wet 2	Spring	32.63 a	18.69 a	2.52 a	0.68 a	54.52 a
Wet 1	Fall	15.61 a	30.65 a	9.68 a	2.88 a	58.85 a
Wet 2	Fall	8.98 a	23.55 b	8.13 a	3.05 a	43.72 a

* Abbreviations and sizes are the same as defined in Table 2.
† Means followed by the same letter within a column for the same season are not significantly different at the 0.05 level using least squares differences and analysis of variance.

TABLE 8. Cultivar effect on fruit size and total yield of marketable tomato fruit, averaged for two excessively irrigated treatments, in 1983

Cultivar	Cropping Season	Size* XL	L	M	S	Total
		----------Mg/ha----------				
'Sunny'	Spring	32.34 a†	20.10 b	2.43 a	0.75 a	55.61 a
'Duke'	Spring	41.39 a	26.81 a	2.38 a	0.17 a	70.75 a
'Sunny'	Fall	15.20 a	39.97 a	14.37 a	4.45 b	73.99 a
'Walter'	Fall	2.51 b	21.50 b	17.27 a	10.19 a	51.47 b

* Abbreviations and sizes are the same as defined in Table 2.
† Means followed by the same letter within a column for the same season are not significantly different at the 0.05 level using least squares differences and analysis of variance.

TABLE 9. Excessive-irrigation effects on firmness, acidity, and soluble solids of tomato fruits in 1983

Treatment	Harvest No.						
	Spring Crop			Fall Crop			
	2	3	4	1	2	3	4
Firmness*	kg/cm^2						
Wet 1	1.88 a†	1.89 a	3.21 a	1.90 a	1.48	1.32 a	1.88 a
Wet 2	1.67 a	1.82 a	3.41 a	1.78 a	2.02	1.58 a	2.15 a
'Duke'	1.70 a	2.11 a	3.26	–	–	–	–
'Sunny'	1.85 a	1.60 b	3.39 a	2.32 a	2.30	1.80 a	2.78 a
'Walter'	–	–	–	1.56 a	1.20	1.28 a	1.64 b
Soluble Solids	%						
Wet 1	4.01 a	4.12 a	4.60	5.02 a	4.78	4.33 a	4.12 a
Wet 2	4.08 a	4.11 a	4.74 a	5.22 a	4.62	4.40 a	4.25 a
'Duke'	3.84 b	3.81 b	4.50 a	—	—	—	—
'Sunny'	4.25 a	4.42 a	4.88 a	4.45 b	4.30	3.98 b	4.15 a
'Walter'	–	—	—	5.51 a	5.10	4.56 a	4.20 a
Acidity	pH						
Wet 1	4.36 a	4.64 a	4.35 a	4.32 a	4.34	4.09 a	4.15 a
Wet 2	4.21 a	4.66 a	4.39 a	4.28 a	4.29	4.01 a	4.06 a
'Duke'	4.30 a	4.53 a	4.35 a	–	–	–	–
'Sunny'	4.28 a	4.77 a	4.40 a	4.22 a	4.25	4.00	4.01 a
'Walter'	–	–	–	4.34 a	4.38	4.07 a	4.16 a

* Resistance to crushing measured with 100-mm^2 flat-tip penetrometer.

† Means followed by the same letter within a column, treatment, and cultivar are not significantly different at the 0.05 level using least squares differences and analysis of variance. Means without letters indicate insufficient data for statistical analyses.

stresses associated with "soft fruit" syndrome. This type of water table response would result in O_2 depletion and physiological root pruning. The injury related release of C_2H_4 from pruned roots is probably the mechanism which accelerates fruit ripening. Accelerated color change and ripening have been shown to be caused by exposure to C_2H_4. Earlier data published from this study would also indicate that traditional physiological plant water stress indices (crop water stress index, leaf press, pressure chamber, and canopy temperature) may be unreliable in these conditions (Sojka et al., 1990). When used to schedule irrigation, they may fail to indicate the need for irrigation early enough to avoid stress levels sufficient to cause yield or quality reductions. Because "soft-fruit" symptoms did not occur in any treatment, even those where excessive irrigation was applied, it appears that an additional factor, possibly in connection with extremely wet soil conditions and/or N fertilizer, may be required to cause these symptoms.

Summary and Conclusions

Water management treatments, including excessive irrigation, were evaluated for a southeastern Coastal Plain soil with a fluctuating water table using different tomato cultivars during spring and fall seasons of 1982 and 1983. Irrigation increased yield only when rainfall was below normal, but when there was a yield response it resulted from a higher percentage of large fruit. This is important because of the premium price received for large fruit. The water table often fluctuated within 1 m of the soil surface, indicating that for some rainfall conditions on this loamy fine sand, it can provide adequate water for acceptable tomato yields. This suggests a lower irrigation requirement for this soil than for a coarser-textured soil studied at the same location in a previous experiment (Camp et al., 1989). Water table depth at this site was adequately represented by the mean water table depth of the seven shallow (< 2 m) wells. As shown previously (Camp et al., 1989), the water table responded predominantly to rainfall with no measurable tidal effect.

Excessive irrigation water was applied with no decrease in yield and no evidence of "soft-fruit" syndrome, thought to be associated with excessive soil wetness and/or N fertilization. The 'Sunny' cultivar performed significantly better than 'Walter' in the fall season for these wet soil conditions.

Two tomato crops were successfully grown on the same beds and with the same irrigation system in both 1982 and 1983. Input costs for this system are higher than for conventional systems, but the practices used in this study can provide increased profitability for fresh market tomato production in the southeastern Coastal Plain, particularly when markets are available for both spring and fall crops.

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References

Camp, C.R., M.L. Robbins and D.L. Karlen. 1989. Microirrigation for fresh-market tomatoes on a high-water-table soil in the southeastern Coastal Plain. *Transactions of the ASAE* 32(5):1582-1586.

Doss, B.D., J.L. Turner and C.E. Evans. 1975. Irrigation methods and in-row chiseling for tomato production. *J. Am. Soc. Hort. Sci.* 105(4):611-614.

Geraldson, C.M. 1975. Evaluation of tomato production efficiency with relevance to contributing components. *Proc. Fla. State Hort. Soc.* 88:152-155.

————. 1982. Intensive production of vegetable crops using the gradient-mulch system. *Proc. Ninth Int'l. Plant Nutrition Colloquium* 1:192-197. Warwick Univ., Commonwealth Agric. Bureaux, England.

Karlen, D.L. and M.L. Robbins. 1983. Management practices for fresh-market tomato production in the southeastern Coastal Plain. *Hort Science* 18(5):732-734.

Karlen, D.L., R.E. Sojka and M.L. Robbins. 1983. Influence of excess soil-water and N rates on leaf diffusive resistance and storage quality of tomato fruit. *Soil Sci. Plant Anal.* 14(8):699-708.

Locascio, S.J., J.M. Meyers and S.R. Kostewicz. 1981. Quantity and rate of water application for drip irrigated tomatoes. *Proc. Fla. State Hort. Soc.* 94:163-166.

Locascio, S.J. and J.G.A. Fiskell. 1983. Changes in available N for drip-irrigated tomatoes from preplant and fertigation N sources. *Soil and Crop Sci. Soc. Fla. Proc.* 42:180-184.

Locascio, S.J., S.M. Olson, F.M. Rhodes, C.D. Stanley and A.A. Csizinszky. 1985. Water and fertilizer timing for trickle irrigated tomatoes. *Proc. Fla. State Hort. Soc.* 98:237-239.

Sojka, R.E., E.J. Sadler, C.R. Camp and F.B. Arnold. 1990. A comparison of pressure chamber, leaf-press, and canopy temperature for four species under humid conditions. *Environ. Exper. Botany* 30(1):75-83.

Soliman, N.F., I.M. Anter and M.F. Soliman. 1978. Effect of depth of water table on growth and yield of tomato. *Agric. Res. Review* 56:17-21.

Stanley, C.D., J.S. Rogers, T.W. Prevatt and W.E. Waters. 1981. Subsurface drainage and irrigation for tomatoes. *Soil and Crop Sci. Soc. Fla. Proc.* 40:92-95

Sweeney, D.W., S.J. Locascio, D.A. Graetz, A.B. Botcher and K.L. Campbell. 1987. Tomato yield and nitrogen recovery as influenced by irrigation method, nitrogen source, and mulch. *Hort Science* 22(1):27-29.